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Teaching Science and Mathematics Subjects Using the Excel Spreadsheet Package

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Abstract

The teaching of scientific subjects usually require laboratories where students can put the theory they have learned into practice. Traditionally, electronic programmable calculators, dedicated software, or expensive software simulation packages, such as *MATLAB* have been used to simulate scientific experiments. Recently, spreadsheet programs have replaced the electronic calculators and are now widely used by science, engineering and mathematics education in modelling and solving complex problems. One of the advantages of a spreadsheet application in science education is that a given problem can easily be modelled and then simulated with varying parameters. The change of the output can then easily be displayed in graphical format as the simulation progresses. This paper describes how spreadsheet programs such as the *Microsoft Excel* can be used for the simulation of digital logic circuits thought to undergraduate students.

Introduction

Effective science and mathematics teaching is very important in all undergraduate engineering and science classes. In UK, students are accepted to Universities based on the results of their *A-Level* examinations. There is strong evidence that most students are opting for easier *A-Level* subjects over the science and mathematics (see Figure 1 and Figure 2). Students usually find the science and mathematics subjects harder and their results from these subjects are generally poorer compared to social science subjects. As a result of the lack of interest in science subjects, there is a serious shortage of specialist physics, chemistry, and mathematics teachers, which has become a barrier to better teaching of these subjects.

There are many reasons for the lack of interest in science subjects. One of the reasons is that these subjects require *creativity*, *positive thinking*, and *problem solving logic*, whereas most of the social science subjects can be learned by memorizing the topics. Perhaps another reason for the lack of interest in science subjects is that these subjects are usually laboratory based and many students have difficulties to carry out real experiments on their own and then present these results in a scientific manner.

Software simulation techniques are currently used by many educational institutions in the teaching of engineering, science, and mathematics subjects. Simulation is usually in the form of a computer program with user-friendly

graphical interface, developed to mimic the operation of a real physical system. For example, the behaviour of an electric motor can be modelled on a computer using a simulation package and students can learn the operation of such a motor on a computer, away from the actual physical laboratory.

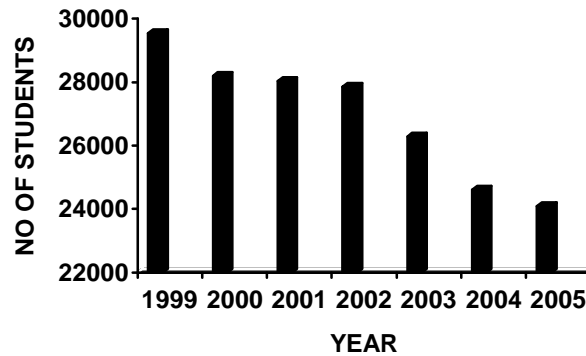


Figure 1. Students taking Physics subjects

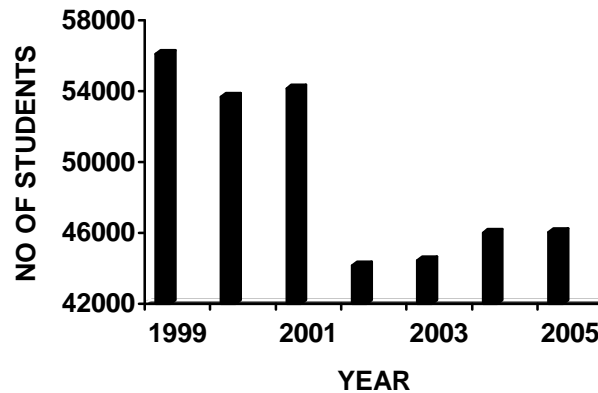


Figure 2. Students taking Mathematics subjects

Although simulation can not replace a real physical experiment carried out in a laboratory environment, nevertheless it has several advantages as outlined below:

- Physical experimental laboratory kits are usually too expensive and many institutions can not afford to purchase such kits. Especially, in a laboratory environment usually more than one kit of the same type may be required and this increases the cost considerably. Simulation on the other hand is simply a computer program and is much

cheaper to purchase and use. In addition, more than one copy of the simulation program can be obtained at reduced cost under special educational licenses and discounts offered by many organisations.

- Physical kits require maintenance and in many cases it can be too expensive to replace faulty components, or to maintain a large number of kits. Simulation on the other hand does not become faulty, and does not require any maintenance, except for occasional software updates, which are usually either free of charge or are supplied at low cost to existing users with maintenance contracts.
- Physical kits may become obsolete in very short time as the technology is advancing very rapidly. It then becomes rather expensive to upgrade or replace these kits. As mentioned earlier, it is very easy and usually a low cost process to apply updates to a simulation program.
- Physical kits can be damaged very easily if they are not used properly. For example, a power supply kit can be damaged beyond repair if the output pins are shorted together. On the other hand, it is not generally possible to damage a simulation program by making wrong selections. The only problem may be the accidental deletion of the simulation program or some of its components. Accidental deletion does not normally happen since most software is protected for deletion. If the simulation software happens to be deleted by mistake, it can be re-installed easily at no cost.
- Software simulation provides access to many variants of a physical entity with no cost. For example, many different models of transistors can be chosen and used in electronic simulation packages. On the other hand, it would be too expensive to purchase many different models of transistors.
- The purchase of a physical kit or a physical component may take long time as it may have to be approved by the finance departments. With software simulation however, any type of component can be modelled and simulated with no purchasing or waiting time.
- One important disadvantage of simulation compared to real physical experiments is that the simulation can sometimes hide the reality from the users. For example, it is very easy in a simulation program to pass a 100A current through a small resistor. But in practice, in a laboratory environment this is very unlikely to happen as the resistor would probably be damaged as a result of excessive heat dissipation.

There are many commercially available simulation packages in the market, developed for engineering, science, and mathematics teaching. Perhaps the most

popular one and the most comprehensive one is the *MATLAB* (2008). Although extremely powerful, MATLAB is a rather expensive simulation package, formed of a base system with many additional *toolboxes* for modelling and simulating various engineering, scientific, and mathematical applications. For example, using MATLAB students can model a complex control system and then easily investigate various controller algorithms to find the optimum one for the system. Similarly, for example, students can perform matrix multiplication or inversion manually and then check their answers using MATLAB. *ANSYS* (2008) is another commercially available simulation package similar to MATLAB and developed for engineering, scientific, and mathematics applications.

Some of the simulation packages are developed for specific applications. For example, *SPICE* (2008), *Multisim* (2003), *EasySim* (2007), *B2Logic* (2008) are developed to simulate electronic analog and digital circuits. Users can model complex electronic circuits using electronic devices, and then the operation of the circuit can be simulated under various input conditions, with the outputs either observed on *virtual instruments* (e.g. a virtual oscilloscope or a virtual multimeter), or plotted as graphics.

This paper describes how the Excel spreadsheet can be used for the simulation of mathematical equations, and also digital logic circuits.

Using Excel in Science, Mathematics, and Engineering Education

The use of spreadsheet programs in science, mathematics, and engineering education is not new.

Aliane (2007) reports the development of a control system teaching package using the Excel spreadsheet program. With the help of this simulation package students can construct computer models of both continuous-time systems and digital control systems. The described package is low-cost and it provides graphical output of the system response where the plant parameters, controller parameters, and the simulation time can easily be modified while the output response is observed dynamically.

Evans (2000) describes simulation techniques using the Excel spreadsheet program. The simulation of a financial system is given as an example where students can modify the price, cost, discount rate, and profit of an item and then observe the expected profit as a dynamic graphical output. Evans report that spreadsheets offer the following pedagogical advantages in learning:

- *Rapid start-up*, where the simulation can be carried out easily after a short course in the general use of spreadsheets.
- *Integrated graphics*, where the extensive graphics facilities provided by the spreadsheet programs can be used in simulation outputs.
- *Dynamic updating*, where new simulation results can be immediately obtained as input data are changed.

- *Statistics integration*, where a full complement of statistical tools and functions provided by the spreadsheet programs can be utilised in simulations.

Pecherska and Merkurjev (2005) describe a spreadsheet-based approach to teaching simulation, where the objective is to introduce spreadsheets as a powerful simulation tool for educational purposes. The paper deals with basic types of simulation models suitable for spreadsheets. The static stochastic or Monte Carlo simulation models are introduced in the paper through a sample model for lead-time demand distribution evaluation. The authors conclude that the spreadsheets provide broad possibilities for creating simulation models for educational purposes in business games, case studies, engineering etc.

Cooper (2002) reports how data analysis and simulation can be carried out using the Excel spreadsheet program. The paper describes how a computer can be used to collect experimental data and then how this data can be analysed using the Excel. The paper also describes how simulation can be carried out with the Excel and how formal worksheets and charts can be developed to present information in *scientific* manner.

El-Hajj, Karaki & Kabalan (2002) present a spreadsheet based method for the graphical simulation of analog computers used in control systems. Analog computers are very expensive hardware devices used to simulate the behaviour of dynamic control systems. The paper describes a simple low-cost method of simulating analog computers using basic building blocks such as adders, integrators, potentiometers, inverters, and non-linear devices. The authors conclude by saying that the proposed method is very convenient for a quick simulation when one does not have the time or means to write a sophisticated program or to access advanced commercially available simulation packages. It is also concluded that the method is sufficiently accurate for a large number of practical applications since Excel stores numbers and performs calculations using 15 digits of precision.

Another interesting paper is by El-Hajj, Kabalan & Mahmoud (2001) where a spreadsheet toolbox is described for simulating digital networks. The paper presents a simulation method using advanced spreadsheet features such as toolbars, menus, controls, graphics, and online help. The authors report that instead of writing lengthy formulas that are spread all around the worksheet, the user can draw a complete logical network by mere mouse clicks. Many examples are given in the paper to illustrate the method presented.

Chemical process simulation using the Excel program is described by Henao and Velasquez (2000). The authors report that using a low-cost tool such as Excel, it is possible to build and solve simulation models that duplicate the results obtained using commercial simulators. It is reported by the authors that a chemical process simulation involves the integration of three basic elements:

- Mathematical models of unit operations
- Thermodynamic properties calculation methods
- Numerical methods for the solution of non-linear equations

Examples are given in the paper on the mathematical modelling and simulation of a chemical plant.

Lundkvist (1997) presents an interactive Excel based method for biology teaching. The aim of the paper is to develop an interactive Excel-application as a pedagogic tool in biology teaching in order to enhance the learning and understanding of dynamic biological systems and complex theoretical sections of genetics. Two simulation tools are presented in genetics, each consisting of a series of modules, intended for demonstration of dynamic biological processes or used as laboratory exercises.

Example Application of Excel in Mathematics

In this section of the paper a simple mathematical application of the Excel spreadsheet program is given to illustrate the simplicity and power of performing dynamic simulation of a mathematical problem. In this example, as shown in Figure 3, the graph of the simple quadratic equation:

$$y = ax^2 + bx + c$$

is simulated dynamically. Students can use a “spin” form control (shown on the left-hand side of the graph) to change the three coefficients a, b, and c of the equation, and the graph is re-drawn dynamically. Thus, students can have an excellent visual understanding of how the shape of the graph varies as the coefficients are changed. Graphs of higher order equations can also simulated very easily and students learn easily the significance of the coefficients of an equation.

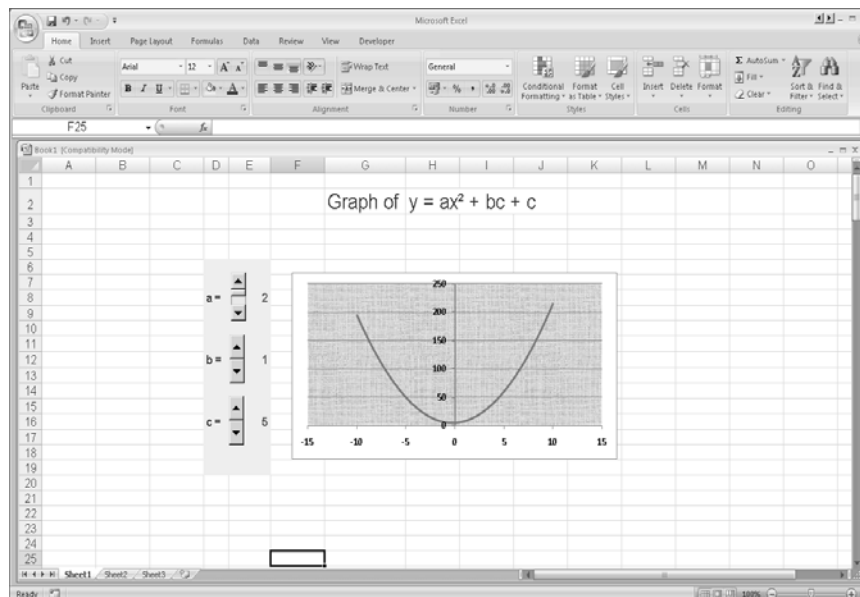


Figure 3. Example application of Excel in mathematics

Example Application of Excel in Physics

This section shows how the Excel spreadsheet program can be used to simulate a physical problem. Here, the equations of motion of a projectile are used to simulate the behaviour of a projectile. If a projectile is fired with an initial velocity of V_o , at an angle of θ with the horizontal, it is well known that the three basic equations describing the range, height, and the flight time of the projectile are given by:

$$\text{Range} = \frac{V_o^2 \sin 2\theta}{g}$$

$$\text{Height} = \frac{V_o^2 \sin^2 \theta}{2g}$$

$$\text{Time} = \frac{2V_o \sin \theta}{g}$$

Figure 4 shows the Excel simulation setup. Here, the picture of a typical projectile path is given with the basic equations of motion under the picture. Students can enter the initial velocity V_o , and angle θ using a “spin” form control. As these parameters are entered, the range, height, time of flight, maximum range, and the maximum height attained by the projectile are all calculated and displayed automatically. In addition, these outputs are also shown in graphical form so that students can see the changes visually and easily.

Conclusions

The paper has described how the Excel spreadsheet program can be used as a useful tool in science, mathematics, and engineering education.

Science and engineering education are more expensive than the social sciences education because of the laboratory requirements. The experimental parts of most science subjects are nowadays carried out using computer based simulation packages. Commercially available simulation packages are very powerful, but at the same time their cost is considerably high. Most of the science and mathematics experiments can easily be carried out by developing spreadsheet (e.g. Excel) based simulators. References to some of the existing spreadsheet based simulators are given in the paper. In addition, examples are given on using the Excel spreadsheet in simple mathematics and engineering based teaching.

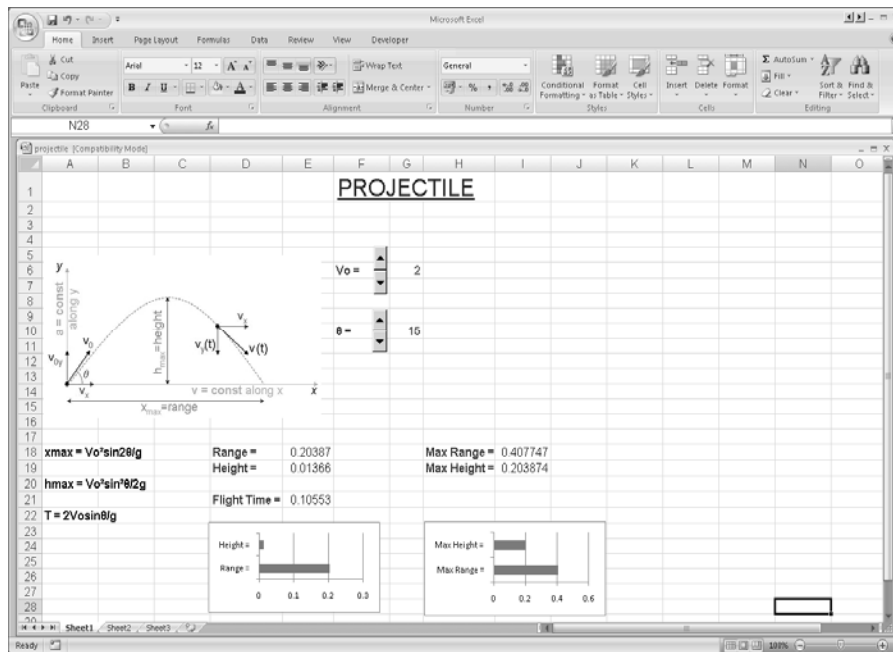


Figure 4. Example application of Excel in physics

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